1990

The use of knowledge-based expert system for landslide hazard evaluation

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THE USE OF KNOWLEDGE-BASED EXPERT SYSTEM FOR LANDSLIDE HAZARD EVALUATION

by

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A Thesis

Presented to the Graduate Committee

of Lehigh University

in Candidacy for the Degree of

Master of Science

in

Civil Engineering

Lehigh University

1990

This thesis is accepted in partial fulfillment of the requirements for the degree of Master of Science.

Dec. 4, 1990

(date)

Professor in Charge

Chairperson of Department

this one for
my wife **ina** *and my son* **abi**

Acknowledgements

I would like to express my gratitude and thanks to faculty of civil engineering, computer science, and industrial engineering from whom I have received educations and guidance through my program, and particularly to Drs. H. Y. Fang and S. Pamukcu with the valuable advice and helps regarding this thesis. My thanks also to fellow students with their suggestions, discussions and friendship which make my stay at Lehigh enjoyable, and to MUCIA which provides the scholarship for my entire MS program.

A. B. Muhiddin

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Abstract

This thesis introduces the use of an expert system, namely Lanse, to help engineers in primary evaluations of landslide hazard. Results of the evaluations are summarized in the form of hazard ratings of the slopes or hillslopes being investigated. Multiple factor approach is used in building the knowledge base. These factors are geology, environment, and human activities. Besides a thorough literature research and expert consultations, knowledge was also obtained from the results of questionnaires distributed to a number of experts in the area of landslides.

Expert system shell used in Lanse is a Turbo Prolog version of Geotox-PC shell which was developed at the Geotechnical Engineering Division, Department of Civil Engineering, Lehigh University. Translation/rewriting into Turbo Prolog was performed in order to gain faster responds. Some modifications were made in the interface part of the shell for a friendlier environment, and in the organization of the coding of the program for better understanding of the flow of control.

The advantages of Lanse are: it can perform landslide evaluation with uncertain and/or incomplete data, and it has the flexibility for user made changes to the built-in expert's hazard assessment in the knowledge base. The flexibility of the knowledge base is necessary either to adapt the system to a specific site's environment or to update its content with future findings in the area of landslides and related topics.

Chapter 1
Introduction

Landslides are problems faced worldwide that cause significant damage to property and engineered facilities and also result in loss of lives. Examples of usual costs which are of concern are damages in buildings, railroads, highways, pipelines, and disruption of construction activities. Therefore landslides have long been the subject of research in the field of geotechnical engineering. A better understanding of the characteristics of landslides will be helpful in avoiding or decreasing the consequences if such a disaster is likely to occur.

Evaluations of vulnerability of slopes or hillslopes against landslides require a unified approach. Assessment solely performed within an isolated model is believed to be insufficient, and may result in misleading conclusions. The number and the probabilistic nature of the factors that might contribute to a slide, increase the complexity of the problem, and may often require subjective experts' judgments. The existing methods of evaluation, such as the analytical methods, have difficulties to incorporate experts' judgments in assessing the stability of slopes. These methods may also require extensive amount of data from the field and the laboratory which may not be readily available, or they may not be economically justifiable to obtain due to the vastness of the area under investigation. An example of such a case may be designing a highway through a hilly terrain. It is perceived that there is a need for a method with a unified approach which would incorporate subjective evaluation and that would work even with insufficient data.

Before costly field and laboratory investigations are conducted, primary evaluations can be performed to classify the sites that are most likely to undergo mass movements. To assist in these primary evaluations, a knowledge based expert system, namely Lanse, was developed.

1.1 Objective

The objective of this thesis is to introduce a knowledge based expert system to assist engineers in primary assessment of landslide hazard of slope or hillslope sites. First the existing methods used in landslide evaluations are reviewed. Then, an alternative approach in dealing with landslide problems is developed by applying an appropriate tool to build the system and by collecting and organizing substantial amount of knowledge and experts' experience.

1.2 Organization of Thesis

The tasks performed in conducting the research involved are: 1) literature research of data and knowledge concerning landslide evaluations, 2) gathering of knowledge, expertise, rules of thumb from experts by consultation and questionnaire, 3) choosing an expert system shell and modifying it as needed, and 4) combining and arranging the knowledge and incorporating it into the knowledge base part of the system.

Organization of this thesis is as follows: Chapter 2 covers aspects relating to landslide and existing method of evaluation. Chapter 3 presents a review of an expert system shell which is used in developing LANSE. Chapter 4 describes the development of the knowledge base, gathering and processing, and methods of data acquisition. And finally chapter 5 presents the conclusions and recommendations for further research.

Chapter 2
Landslide Evaluation

2.1 Causes of landslides

A large number of factors such as geological and hydrological conditions, topography, climate and weathering may affect the stability of slopes [Broms and Wong 91, Varnes 78, Sidle et al 85, Crozier 89]. A general classification of factors causing landslides is shown in Table 2-1 [Rib and Ta Liang 78].

Number and types of factors that actually exist in the area of landslides maybe less than those listed in Table 2-1. They will depend on locations, hemispheres, which also constitute the differences in climatic or environment conditions and other characteristics of the areas. As an example, earthquake maybe one of the most damaging factors for one area with frequent occurrence of earthquakes, but this natural phenomena may never be considered even as a slight factor for another region. Degree of contribution of each factor may also differ significantly from one to another in the same area.

There often is a relation and hierarchy of importance among the factors that contribute to a landslide. Since the variability of each factor depends on location, such as different hemispheres, regions, or even sites of concerned, it will be incorrect to consider the same set of relations between factors of all areas. However, within a limited area where geological and environmental conditions are more or less the same, these factors may have the same relative level of significance in causing landslides.

Factor	Element	Examples
Geologic	Landform	Geomorphic history; stage of development
	Composition	Lithology; stratigraphy; weathering products
	Structure	Spacing and attitude of faults, joints, foliation, and bedding surfaces
Environmental	Climate and hydrology	Rainfall; stream, current, and wave actions; ground water flow; slope exposure; wetting and drying; frost action
	Catastrophes	Earthquakes; volcanic eruptions; hurricanes, typhoons, and tsunamis; flooding; subsidence
Human	Human activity	Construction; quarrying and mining; stripping of surface cover; over loading, vibrations
Temporal[a]		

[a]Common to all categories and factors

Table 2-1: Basic factors considered in evaluating terrain, after [Rib and Ta Liang 78]

In practice, for a given area, the slope evaluations will be very complicated if all of the factors in Table 2-1 are considered. An example of the *human activity* element in the table maybe acid rain, a by-product of industrialization. Although it seems remote and the effect of which too small compared to other factors, it maybe significant factor for sites affected by such a condition, since acid has been proven to affect the shear strength of soils. In essence, a large number of variables should be included if all possible landslide causing factors are considered. Therefore records and studies of past landslides are needed in order to recognize fewer governing or dominant factors causing landslides.

Experts acquainted with an area may easily narrow down their attention to these governing factors that affecting slope stability of that particular area or of other analogous sites. Some cautions should be applied in selecting these fewer number of factors. One factor may sometimes mistakenly be selected as the single cause of the landslide, such as rainfall, which is actually the triggering factor that start an already susceptible terrain prepared for a possible slide by other factors. For example, in a tropical area, landslides generally happen during or after the wet season or after a long duration of rain. But for the same degree of wet season or the same rain intensity and duration, an area which is known with severer clear-cutting or steeper slope have a greater chance to undergo more or severer landslides. By looking back to the history of that area, it may be found out that the increasing number or volume of mass movement actually began after the clear-cutting of vegetative cover. Therefore inappropriately focusing attention to a few factors may underestimate other more important factors. So considering the correct number and type of factors is essential for the final integrity of an assessment made about stability of a terrain.

2.2 Existing methods of landslide evaluations

There have been efforts to evaluate regional areas of their susceptibility to mass movement. An example is the USGS (U. S. Geological Survey) method of slope stability rating for San Francisco region [Nilsen et al 79]. This method considers three important factors: 1) slope, 2) bedrock geology, and 3) the landslide history of the area. From evaluation of three different methods namely USGS, OCAP (Ohio Capability Analysis Program), and Tal's method, it was shown that USGS method predicts the landslide susceptibility most closely [Gordon and Klousner 86]. Table 2-2 presents the comparison of these three methods. It should be noted that this table is only part of the original table presented in that study. USGS method was the only method which considered landslide history as one of the important factors. Therefore, it was suggested by the investigator to include this factor in any landslide evaluation. Since USGS study was conducted at a regional level, consideration of only three factors was justified for lack of more detailed data from this large area. For a site which is much smaller in size, more specific data or factors should be involved to add higher level of confidence to the final conclusion.

From the previous studies, it can be noticed that there are three main differences between the three methods listed in Table 2-2, i.e.: 1) number and kinds of factors or variables which are considered important in the process of evaluations, 2) number and types of categories which are used to classify the factors, such as ranges of values or present and not-present description, and 3) qualitative hazard levels used to described the severity of stability conditions, for example terms such as unstable, severe, or high susceptibility for extreme instability. On the other hand Table 2-2 also shows agreement on certain factor which in this case is the slope category. Another approach used in qualifying the condition of sites is presented in Table 2-3. This table presents a less straight forward classification since the descriptions of some of the classes indicate that the method requires still another analysis.

It is worth to mention another type of effort, which is somewhat different than a landslide hazard evaluation. It is the warning systems for the San Francisco Bay region [Keefer et al 87]. The warning system is based on empirical and theoretical relation between rainfall and landslide initiation, real-time regional monitoring of rainfall data, weather forecast, and map of landslide susceptible area. This system also shows that there is some empirical relation between a factor, in this case the rainfall, and landslides for a region and that the map of landslide susceptible area can be an acceptable guide.

Model	Variable/criteria	Hazard level
OCAP	Soil type[a]	
		Slight
		Moderate
		Severe
	Slope category	
	0%-3% or 0%-8%	Slight
	0%-15% or 8%-15%	Moderate
	8%-25% or >15%	Severe
	Permeability (inches/hr)	
	>2.0 or >6.0	Slight
	0.2-2.0 or 0.6-6.0	Moderate
	0.2-0.6 or <0.6	Severe
	Shrink-swell potential	
	Low	Slight
	Medium	Moderate
	High	Severe
USGS	Slope	
	0%-5%	Stable
	6%-15%	Generally stable
	>15%	Marginally stable to moderately unstable
	Susceptible bedrock type	
	Not present	Stable
	Present	Marginally stable to moderately unstable
	Landslide deposit	
	Not present	Stable to moderately unstable
	Present	Unstable
Tal	Vegetation	
	Not present	Medium to very high landslide susceptibility
	Present	No, conditional, or low landslide susceptibility
	Slope	
	0%-4%	No or conditional susceptibility
	4%-12%	Low susceptibility
	12%-18%	Low to medium conditional susceptibility
	>18%	High to very high susceptibility
	Soil type[b]	
		Type not present
		Type present

[a]based on the presence or degree of the following soil characteristics:texture(clay or silty clay); hillslope position(coves and footslopes of concave hills); bedrock(shale or claystone); and stripmine soil.
[b]soils with loam texture;and soils located on hillsides/slopes, on rolling lands(5% to 10% slopes), and on terraces or benches.

Table 2-2: Variables by final Hazard level for the OCAP, Tal, and USGS models - partly adapted from [Gordon and Klousner 86]

Class VI	Slopes with active landslides. Material is continually moving, and landslide forms are fresh and well-defined. Movement maybe continuous or seasonal.
Class V	Slopes frequently subject to new or renewed landslide activity. Movement is not regular, seasonal phenomenon. Triggering of landslides results from events with recurrence intervals of up to five years.
Class IV	Slopes infrequently subject to new or renewed landslide activity. Triggering of landslides result from events with recurrence intervals greater than five years.
Class III	Slopes with evidence of previous landslide activity but which have not undergone movement in the preceding 100 years. <u>Subclass IIIa</u> Erosional forms still evident <u>Subclass IIIb</u> Erosional forms no longer present - activity indicated by landslide deposits.
Class II	Slopes which show no evidence of previous landslide activity but which considered likely to develop landslide in the future. Landslide potentially indicated by stress analysis, analogy with other slopes or by analysis of stability factors; several subclasses maybe defined.
Class I	Slopes which show no evidence of previous landslide activity and which by stress analysis, analogy with other slopes or by analysis of stability factors are considered highly unlikely to develop landslides in the foreseeable future.

Table 2-3: Landslide Probability Classification [Crozier 89]

2.3 Method of analysis

Determination of stability of slopes or hillslopes is a complex problem due to a large number of factors that might be involved and the gradual or sudden changes of these factors. More often do mass movements or slope failures occur under extreme changes of environments.

The existing slope stability analyses is not yet an appropriate method to deal with problems of landslides. The assumption of linear elasticity which is used in the analytical methods, is considered to be a poor model of soil [Morgenstern and Sangrey 78]. In the case of rock, interrelationship of unknown parameters, complicate the application of static analysis [Zaruba and Mencl 82].

In addition to its inherent weakness, a static analysis method has some other drawbacks to be used for a landslide evaluation if available funds and experts become the decision makers. The analytical methods require well defined layers and their thicknesses since analysis of rugged and varied layer thicknesses will increase the complexity of the analysis. For some methods, assumptions of types of movements such as circular, log-spiral, or translation are required to perform the analytical evaluations. But the assumptions made in calculation must always be checked and any peculiarity of the site must be realistically assessed [Legget and Karrow 83]. However, in many cases, the outer limit of a ground movement, which is also assumed in calculation, is not known [Wilson and Mikkelsen 78]. To obtain this information thorough field investigations and subsequent laboratory tests are necessary so that the model used will closely represent the actual site conditions. But, such an investigation may not be economically justified for all sites, for example, a vast area covered in construction of a highway through a hilly terrain. In addition to these problems, the changes in environment or conditions will require repeated calculations to incorporate these changes.

Due to a large number of factors involved, slope or hillslope stability evaluation may be very complex. The accuracy of an evaluation is never guaranteed [Peck 75]. Even a detail study can never guarantee the stability of all slopes for most large constructions [Rib and Ta Liang 78]. However the current knowledge of landslides allows most experts to closely evaluate slope stability even though the evaluation involves uncertainties. These uncertainties suggest a study of using a probability method for assessing landslide hazard. Factors influencing landslides occurrence vary in a more or less predictable manner which allows us to identify zones in maps with different degree of landslide hazard [Crozier 89]. According to Crozier there are five tasks involved in identifying these zones:

1. identification of the nature, degree of activity and critical level of <u>external destabilizing factors</u>;
2. identification of physical response of inherent factors to the critical levels of activity of the external factor; that is a determination of <u>terrain sensitivity</u>;
3. integration of both the frequency of the occurrence of critical levels of the external factors and terrain sensitivity to produce a measure of the <u>probability of landslide occurrence</u>;
4. combination of the probability of landslide occurrence with mass movement characteristics, such as rate, depth , volume, and zone of influence to produce an assessment of <u>potential landslide hazard</u>. In effect, this is a statement of the frequency/magnitude characteristics of the phenomenon;
5. combination of potential landslide hazard with potential human, economic and environmental damage to produce a statement on <u>landslide hazard risk</u>.

In this research, items one through four are are implemented in different ways as they will be discussed in the following. The first and second items, determination of *external destabilizing factor* and *terrain sensitivity*, will be presented as groups of factors in the knowledge base which either increase shear stress, or cause low or decreased shear strength.The third task, producing a measure of the *probability of landslide occurrence*, will be presented by using confidence level. The fourth, producing an assessment of *potential landslide hazard*, will be shown as hazard values which indicate the classification or degree of severity of a certain factor. From the above items only the last task has not been utilized in this system. Inclusion of variable of damage consequences of landslides to human, economic and environmental is beyond this research although such an addition to the system is possible in the future. Further discussion on how the four tasks are implemented into the system will be presented in the following chapters.

First a "tool" is selected to perform the four previously mentioned tasks. Using the AI(Artificial Intelligent) techniques applied in Geotox-PC [Mikroudis and Fang 88], a new knowledge-based expert system was built. Geotox-PC uses Bayes' theorem and confidence levels in making conclusion/evaluation, and is able to perform under incomplete data/input, which is a situation to be most likely encountered in landslide problems. Geotox-PC is a micro computer version of larger system, namely Geotox, which runs in a VAX station. Geotox performs as a surrogate consultant for evaluating waste disposal sites. In the next chapter some important features of Geotox and the reasons for choosing it as the "tool" for this thesis will be presented.

Chapter 3
Expert systems shell

3.1 Choosing a shell

Some factors were considered in choosing a tool, expert system shell, for this thesis. The first factor is the nature of the problems and the selected approach in dealing with the problems. As described in the previous chapter, probabilistic approach is used in this landslide hazard evaluations. Problems will involve interpretation of site characteristics and classification of the potential landslide hazard. Results of the evaluations will be presented in terms of severity of the conditions and their associated confidence levels. Therefore a system shell that is equipped with a diagnostic and probabilistic capability is suitable for this problem. The second factor is the capability of the system to be used on machines ranging from a desktop microcomputer to a more sophisticated hardware system such as mainframe, without major modifications on system's logic or flow of control. The other factors that contributed to the selection are the availability of the program's source code, capability of the programmer to handle the system shell, and the time constraint in finishing the research.

Considering the above factors, Geotox-PC shell was selected in this thesis. Geotox-PC shell is the Geotox-PC minus its entire knowledge base. Geotox-PC shell is a interpretation, classification, and diagnostic type of expert system. It uses probability in its inference mechanism in terms of confidence levels. It also uses Prolog (PROgramming in LOGic) language which is applicable for broad varieties of hardwares, from microcomputers to general purpose scientific workstations [Mullarkey 87]. Transporting the program from one machine to the other is possible if such a need occurs. Lastly, the program's source code of Geotox-PC is available in the Geotechnical Engineering Division, Department of Civil Engineering, at Lehigh University.

3.2 Review of Geotox

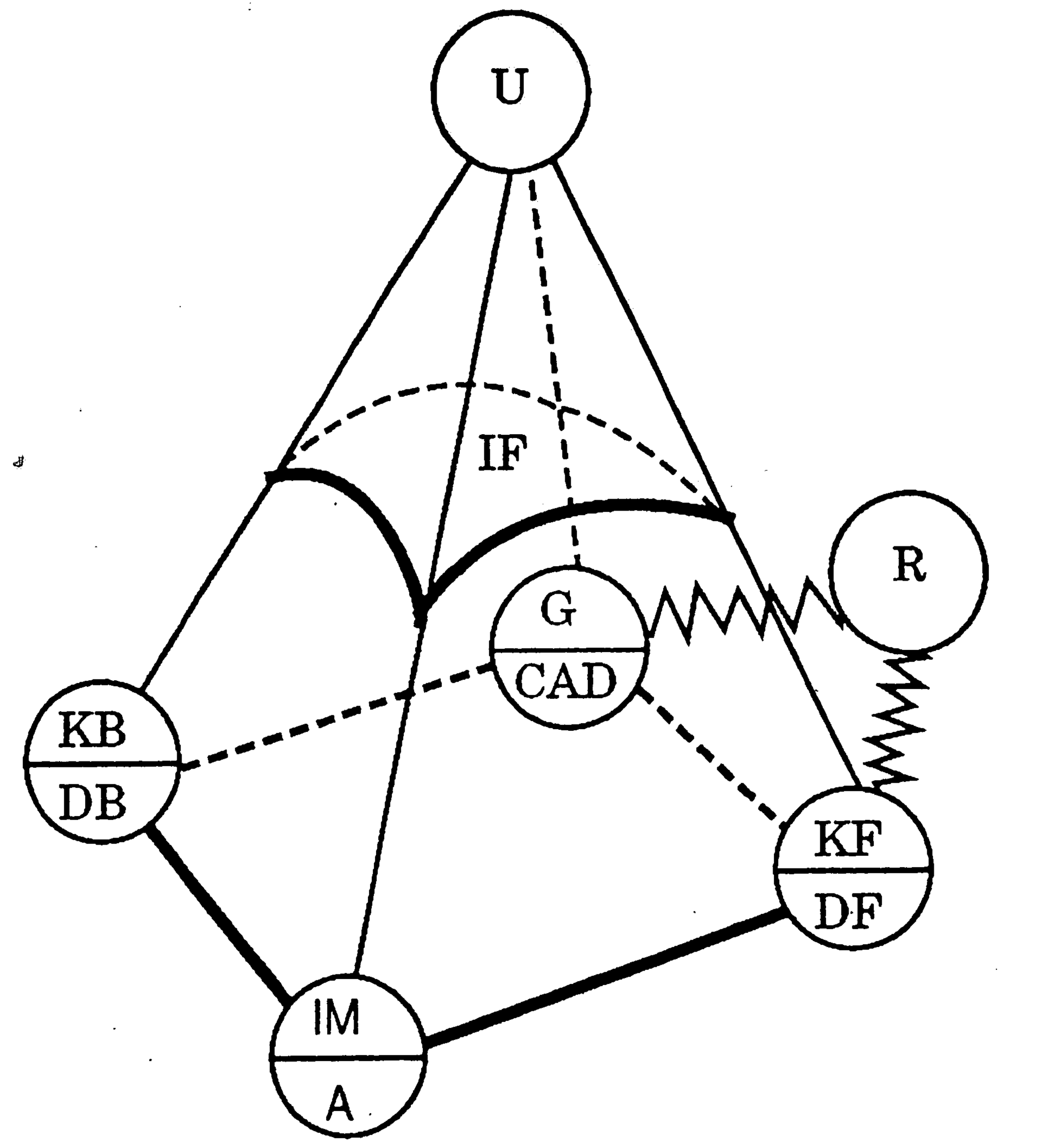
In this section only some important features of Geotox will be briefly reviewed. For more detailed description of Geotox and Geotox-PC can be seen in the original works [Mikroudis 86, Mikroudis and Fang 88]. Figure 3-1 is the conceptual model of Geotox. The figure shows the main elements of the Geotox model. But compared to this conceptual model, Geotox-PC does not include the hardware for remote sensing, and has limited graphic capabilities. Important elements of Geotox or Geotox-PC which will be reviewed in this chapter are: 1) Knowledge representation, and 2)Inference mechanism. Understanding the two elements is considered crucial in order to utilize Geotox or Geotox-PC shell for other problem domains.

3.2.1 Knowledge representation

There are three different methods in knowledge representation namely: 1) Associative Network, 2) Production rules, and 3) Frames. These methods are schematically shown in Figure 3-2 and briefly described at the followings.

Associated Network
provides the structure of the overall knowledge. It defines the association between data and site parameters. *Nodes* represent site characteristics and *links* represent relationships between those characteristics. Links can either be disjunctive or conjunctive.

Production rules are used in leaf nodes and conjunctive nodes to represent expert derived heuristics. They express estimated hazard level by using hazard value and confidence level.



FEATURES	BENEFITS
KB: KNOWLEDGE BASE	
* PRODUCTION RULES (for expert derived heuristics)	Modularity, simple semantics, easier knowledge acquisition
* SEMANTIC NETWORK (defines the problem solving strategy, and parameter interactions)	Cause-effect relationships, classification properties easily described
* FRAMES (for conclusions and recommendations)	Various types of evaluations, possible situations defined
IM: INFERENCE MECHANISM	
* CONFIDENCE FACTORS	Expresses confidence in data
* COMBINATION OF FORWARD AND BACKWARD CHAINING	Handles both interpretive and diagnostic problems
IF: INTERFACE	
* HOW/WHY	Examine the line of reasoning
* SUMMARIZE/CONCLUDE	Review the state of knowledge
* VOLUNTEER	Flexible data entry
* CHANGE	Data update
* REVISE	Modify the knowledge base
KF and DF: KNOWN FACTS and DEDUCED FACTS	

User specified options include:

G: COMPUTER GRAPHICS	Visualization of conditions
DB: DATA BASES	Access to data bases
A: ANALYSIS PROCEDURES	Use of analytical models
CAD: COMPUTER-AIDED DESIGN	Links to CAD programs
R: REMOTE SENSING	Ability to incorporate remote sensing device

Figure 3-1: Features and benefits of GEOTOX Shell

Frames are used to represent final conclusions by using values of nodes which are connected to the slots.

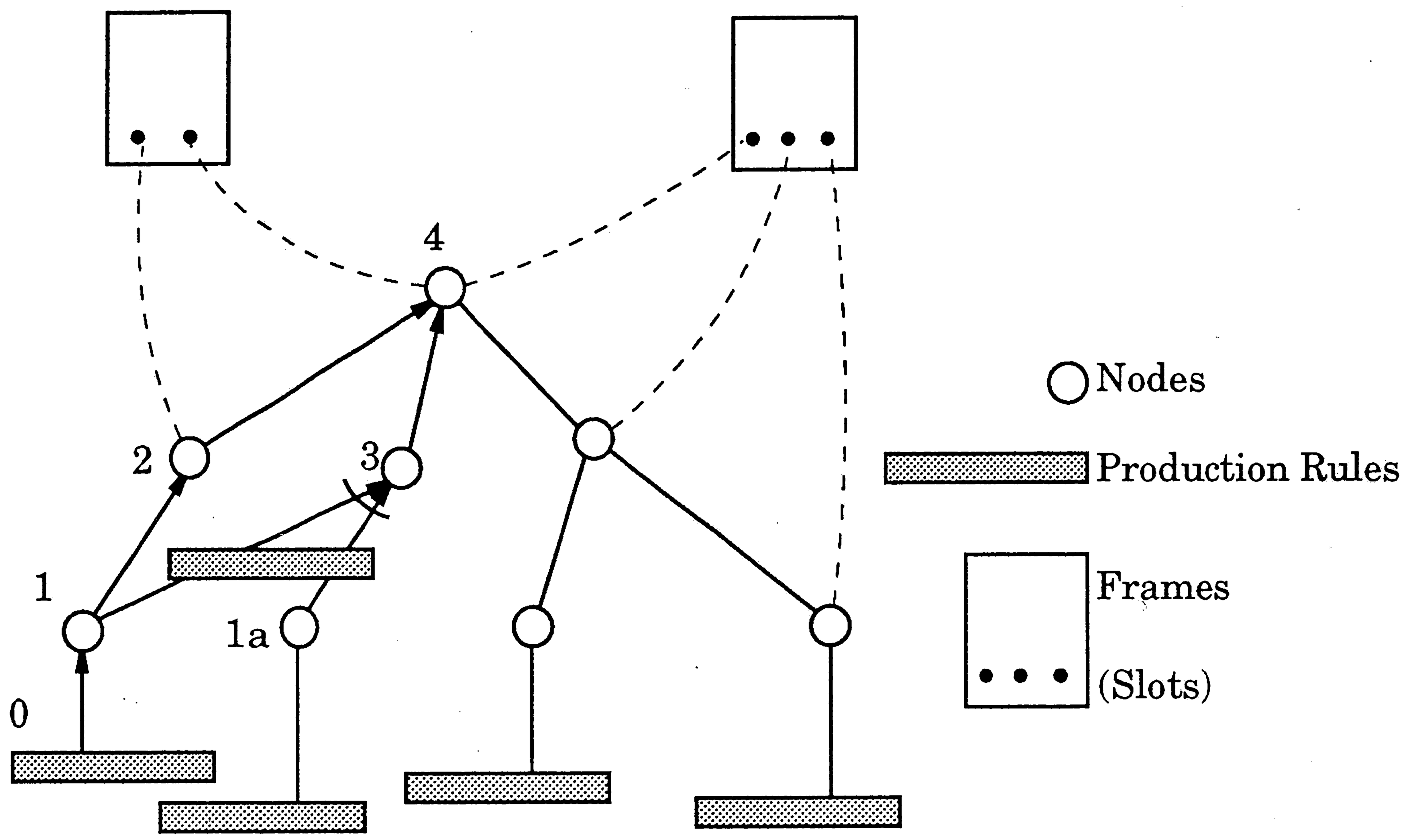


Figure 3-2: Node Updating in the Associative Network of GEOTOX Shell

3.2.2 Inference mechanism

Geotox uses hazard index H (0-10 scale) to describe the severity of conditions. H to a certain extent is affected by every associated site characteristics which are indicated by subindex h_i, as shown in Figure 3-3. Data supplied in the leaf nodes will assign a pair of hazard value (h) and confidence level (c) to these leaf nodes (nodes which have no offspring nodes). Each leaf node is connected to one or more parent(s) which will inherit the h-c pair. For disjunctive parent-son relation, such as node 2 or 4 in Figure 3-2, and no other h-c value in the parent node, h-c value from leaf node is simply assigned to the parent node. If h_o-c_o value already exists at parent node, a new pair will be assigned by applying inference rule according to Formula 3.1 through Formula 3.4, this type of updating is illustrated in Figure 3-4.

$$s=N(c),\quad s_o=N(c_o) \tag{3.1}$$

$$\frac{1}{s_n^2}=\frac{1}{s^2}+\frac{1}{s_o^2} \tag{3.2}$$

$$h_n=\frac{(hs_o^2+h_o s^2)}{(s^2+s_o^2)} \tag{3.3}$$

$$c_n=N^{-1}(s_n) \tag{3.4}$$

where s is the standard deviation of a normal distribution N
with a probability of c between h-0.5 and h+0.5

Figure 3-4 shows that the more pieces of evidence which are associated to a node available, the higher confidence level will be assigned to that node. For conjunctive relations, such as node 3 in Figure 3-2, the assignment of values will follow the rules of that nodes. The propagation of the *h-c* pair will continue upward until all the associated nodes are updated. And for every single data supplied at the leaf nodes, all their associated parent nodes and beyond will be updated *only once*. The only node which is always updated for every input is the upper most node in the network. Pair of values in this node are called the overall hazard value and confidence factor. To reach a conclusion, it is not necessary that all the leaf nodes be filled. The unanswered nodes are simply not included in the evaluation without affecting the process of drawing conclusion. This feature allows a consultation with incomplete data, but with a lower confidence level of the conclusion.

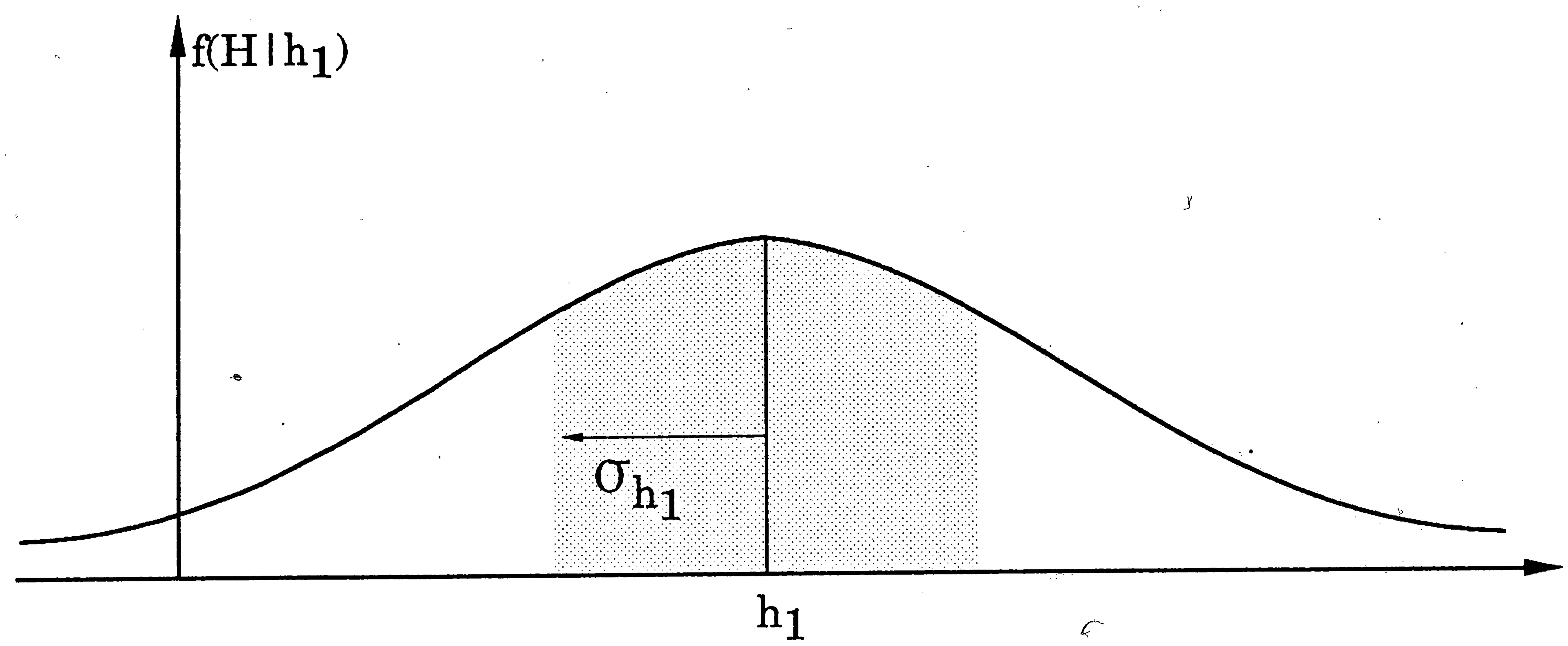


Figure 3-3: Conditional Density of Overall Hazard H Based on Measured Value h_1

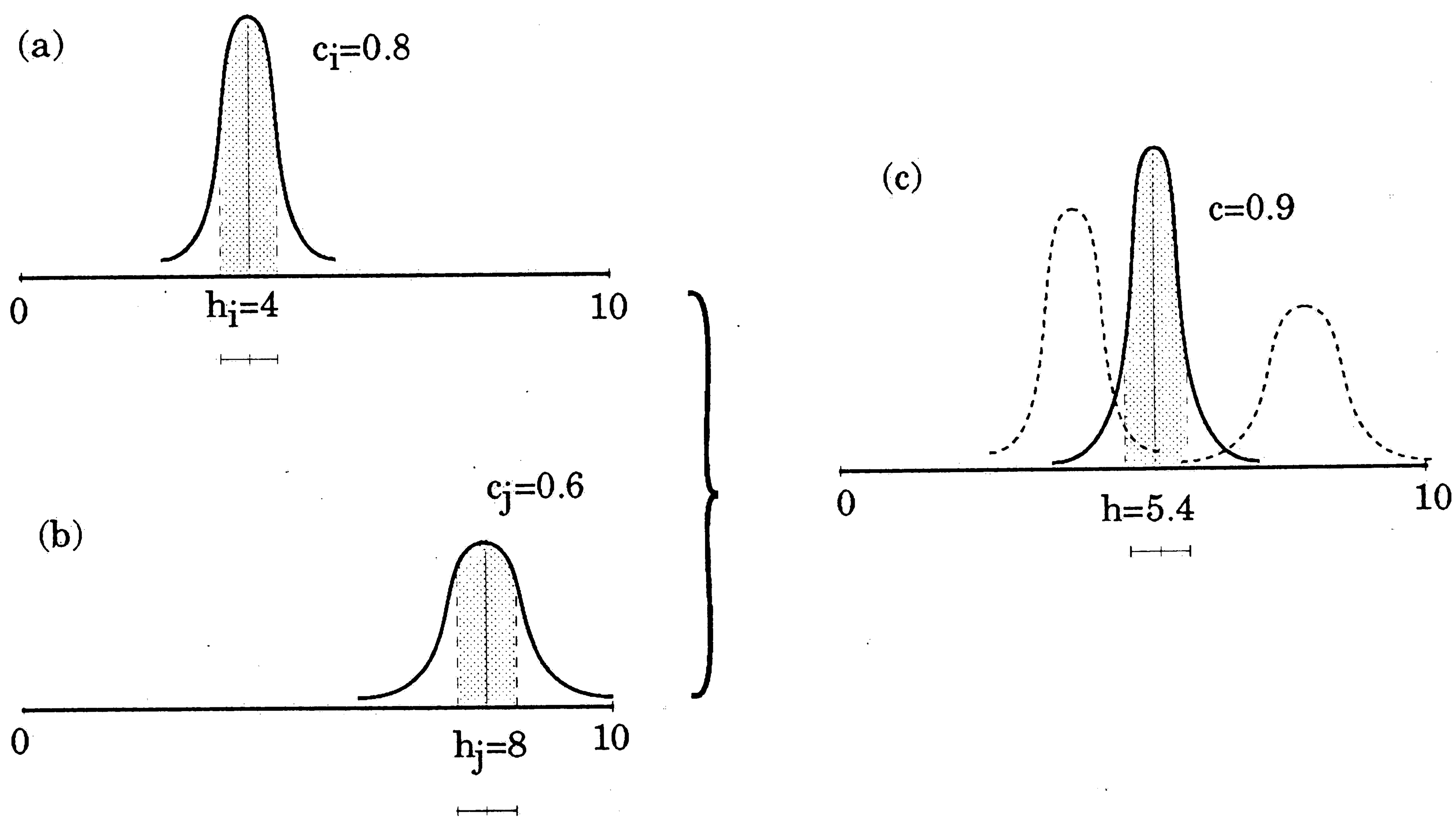


Figure 3-4: Application of the Inference rule in GEOTOX Shell

3.3 Lanse shell

Different from Geotox, Geotox-PC is not equipped with the capability which allows it to provide a software development environment to be used for other environmental geotechnology applications. Therefore the development for other domain problems should be performed within a programming language environment. In this project, instead of ADA Prolog, Turbo Prolog version 2.0 is used to rewrite the entire Geotox-PC shell for two reasons: firstly, to gain shorter response time, and secondly for convenience since Turbo Prolog programming software and its documentations were available in all computing sites at the Lehigh University. There are some important differences between ADA Prolog and Turbo Prolog i.e.:

- Differences in predicate declaration, such as a certain predicate name should have a certain number of arguments in Turbo Prolog, while in ADA Prolog the same predicate name can have a different number of arguments.
- The difference in built-in predicates/standard predicates which are available in the two types of Prolog, in Turbo Prolog some predicates should be created to replace the function of ADA Prolog-standard predicates which are used in Geotox-PC.
- Turbo Prolog does not utilize infix clauses.

Rewriting of Geotox-PC shell from ADA Prolog into Turbo Prolog version 2.0 (by using [Borland Int. 88] and its Toolbox) was completed with three modifications which will be described in the following sections.

First modification is that the clauses are arranged such that the flow of control or logic can be easier to read by a programmer simply by examining the program's source code. This was done in two steps. First step, program code is separated into parts according to the options in the menu, for instance clauses which execute **go** option were gathered and put together in a separate file. And the second step, by putting all clauses *as much as possible* directly after or close to their calling clauses. Figure 3-5 gives illustration of this arrangement. An advantage of using this arrangement is that it eases error findings and facilitate future modifications even by different programmer.

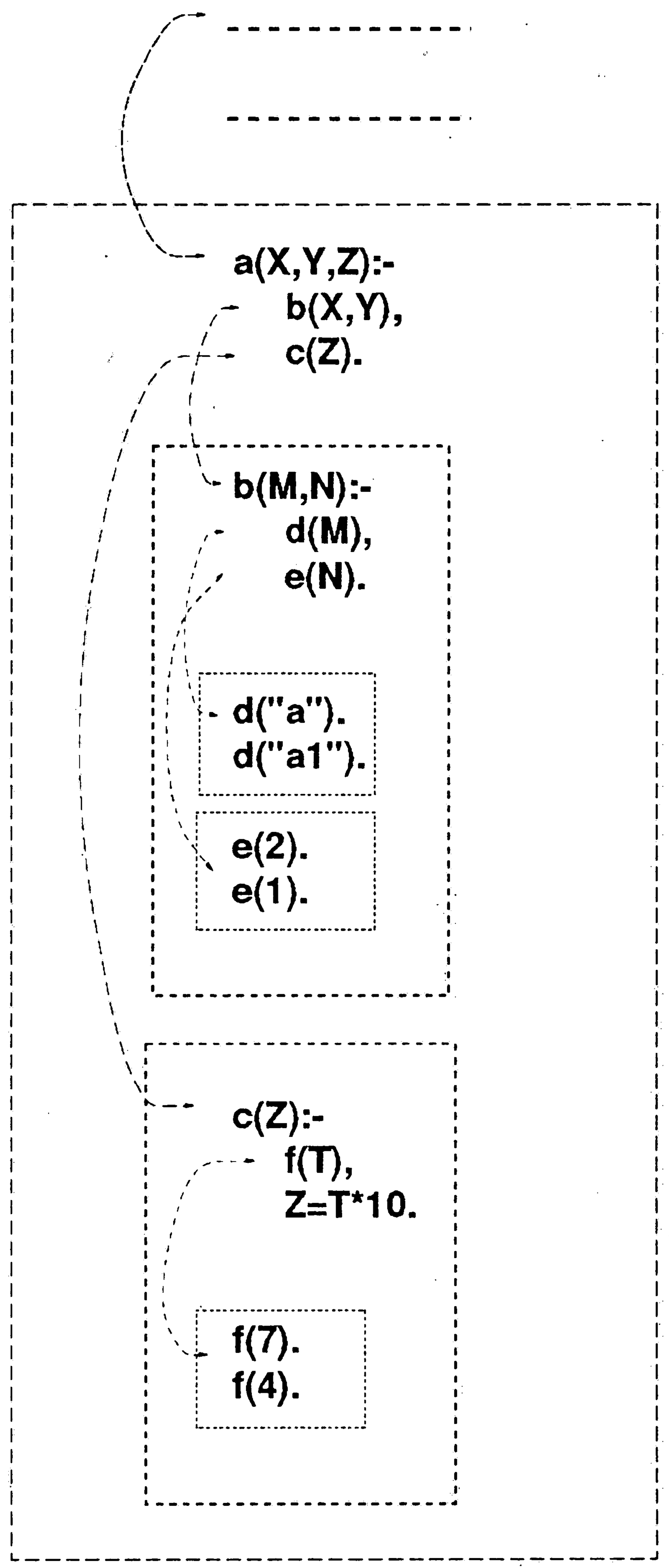


Figure 3-5: Illustration of structure used in coding of Lanse

Second set of modifications are in the interface part of the system, i.e.: 1) modification in the status line, 3) addition of dialog to some options, and 3) rectifying a coding which result in the stoping of the execution of the program. Refinement of the status lines (message line in the last row of the screen) was done such that at any point the messages are always relevant to the options or sessions being executed. Changing from one option to another options will automatically change the message in the status line. The other modification of the interface is the addition of dialogues. For user convenience some mechanism have been added to a number of options such that if the user is asked to supply a node name and he/she gives the wrong one, the system will give a message to the user concerning the input given. The improved options are: "delete relations", "delete rules", "volunteer", "change", "add rules", "how", "show relation", and "show rules". Error of coding has been found in the Geotox-PC shell which at some point will stop the running of the program, that is if the option "delete relation" is selected and the user types 'h' to see the tree graph of the relation being deleted. This error has been corrected in the program.

The third modification was in the inference mechanism. In Geotox-PC, values of confidence factors which are presented by executing options "summary" and "conclude" are not the same with those presented by options "how" and "show rules" for the same factors. The former are a little higher than the latest. It was found that in the translation of formula 3.4 into computer coding a sign was forgotten. The coding causes the presented confidence values to be higher than their intended values. These differences have been rectified in the Lanse's source code. Table 3-1 shows the comparison of values of hazard level and confidence factors between Geotox-PC and Lanse (by using Geotox knowledge base) after first data was supplied to the system. After the first supplied piece of evidence, it is shown that in "summarize" option the confidence level is 0.37 while in the "How" and "Show rules" the confidence level is only 0.36 in Geotox-PC. These differences do not occur in Lanse with the Geotox knowledge base.

First factor: Population Within 1000 feet I > d. more than 100 people.	Lanse with GeotoxPC data base	GeotoxPC
Option:		
>Summarize		
Score	8.75	8.75
Confidence level	0.36	0.37
>How		
Site hazard	8.75	8.75
Confidence level	0.36	0.36
>Show rules		
Site hazard	8.75	8.75
Confidence level	0.36	0.36

Table 3-1: Comparison of Lanse and Geotox-PC on confidence level

Basically all the processes during the execution of the system can be summarized in a loop as follows: a)update the network, b) check priorities, c) ask questions, d) get new data or satisfy a user request, and e) go to a). The overall flow of control or options in Geotox-PC or in Lanse is presented in Figure 3-6. Description of each item in this graph is presented in Figure 3-1 except for "what" and "comment". "What" is an explanation facility which paraphrases the questions posed to the user, and "comment" is a facility that is provided for the user to put a note concerning a specific factor.

Geotox knowledge base was temporarily applied during the rewriting/translating of the program, and checking whether the program works or not. When this part of the research was completed, the next step was initiated, which was gathering and organizing the knowledge base of the

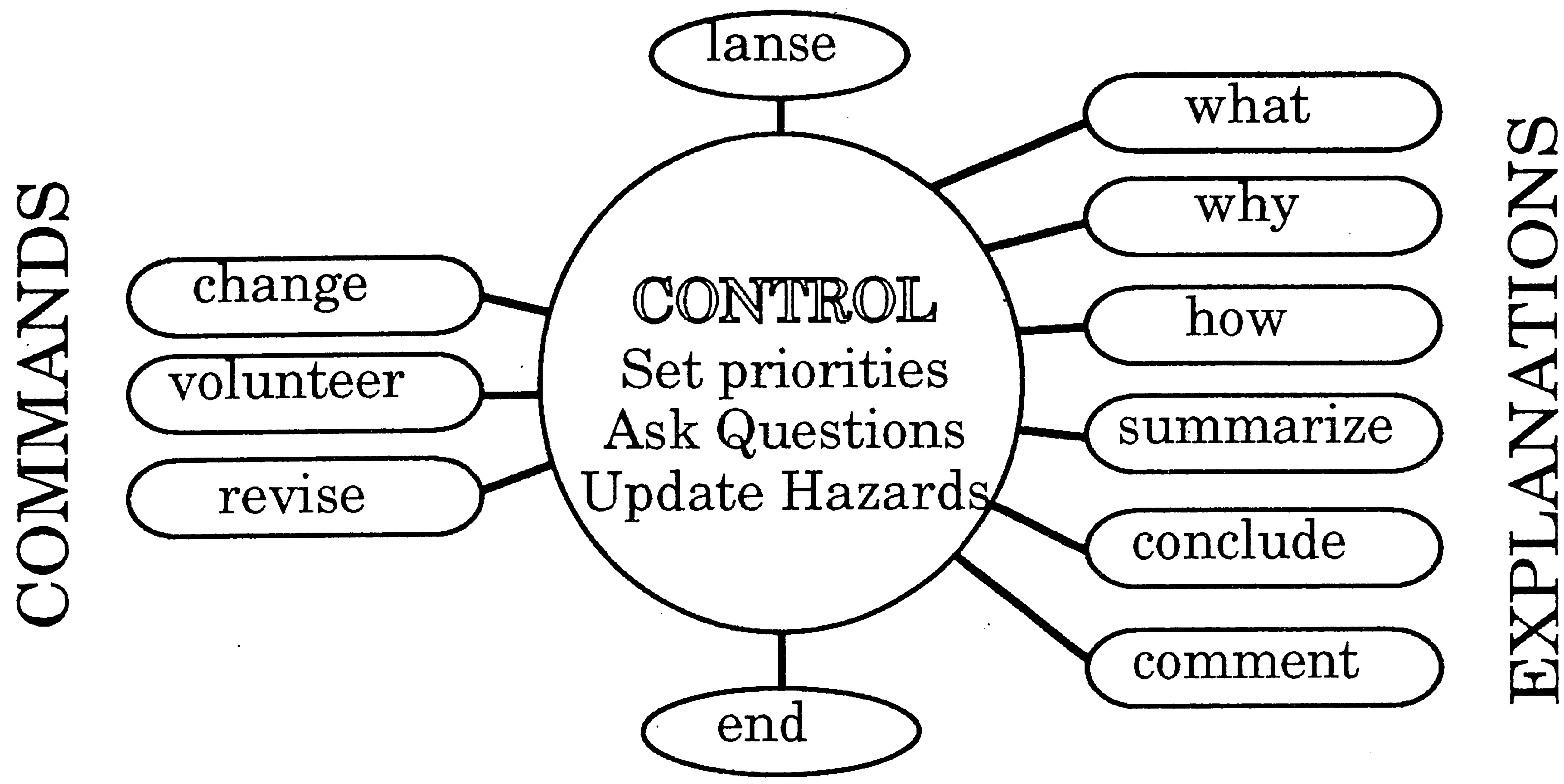


Figure 3-6: Flow of control in Lanse - Geotox-PC shell

landslide problems and then incorporating it into the system. This step will be covered in the next chapter.

Chapter 4
Lanse knowledge base

4.1 Building knowledge base

The main objective of the system is to provide the user with a hazard rating of a suspected site. Conclusion is presented by translating scores of hazard values and confidence levels into four qualitative hazard ratings, i.e. :

- no hazard
- slight hazard
- moderate hazard
- high hazard

There were several steps performed in building up the knowledge base, i.e. :

1. setting up a structure of the factors which are considered in the process of landslide evaluations,
2. establishing classifications within the factors, and
3. determining the contribution or level of importance of each factor to the final conclusion.

Each of these steps will be described in the following paragraphs. Types of resources used in these steps are from literature research, informal consultations, and from distributed questionnaires.

4.1.1 Structure of the knowledge base

Implementation of a knowledge base expert system to solve landslide problems demanded a systematic presentation of the knowledge. Knowledge organization of the expert system presented here consisted of the following three major groups:

1. Factors that contribute to increased shear stress.
2. Factors that contribute to low or reduced shear strength.
3. Indicators of instability.

The first group is identical with the term *external destabilizing factors*, while the second group is equivalent with *terrain sensitivity*, and the content of the third group more or less can be classified as *terrain sensitivity* [Crozier 89]. These groups groups are adopted from a classification of landslide factors by Varnes [Varnes 78]. Only parts of that classification are incorporated in the development of this knowledge base. The main reason for exclusion of some of the subgroups was to reduce the complexity of the evaluation process. To compensate this exclusion, a third group was introduced, namely the indicators of instability. Each group contains of a number of factors or site characteristics, or consists of a subsequent division. The end branch factors or leaf nodes total to 21 site characteristics. Figure 4-1 presents the complete diagram of *current* organization of factors used in landslide evaluation in the knowledge base. This diagram also constitutes the *nodes* and *links* which are part of the associative network of the knowledge representation.

4.1.2 Classification within factors

After setting up the organization of factors, the next step is classifying the conditions within the same factor, and assigning scores to these conditions. The latter exercise constitutes the determination of the *production rules* which are applied to that factor. Scoring is considered the most difficult part in building up a knowledge base. Usually in the event of few supporting data or of complex

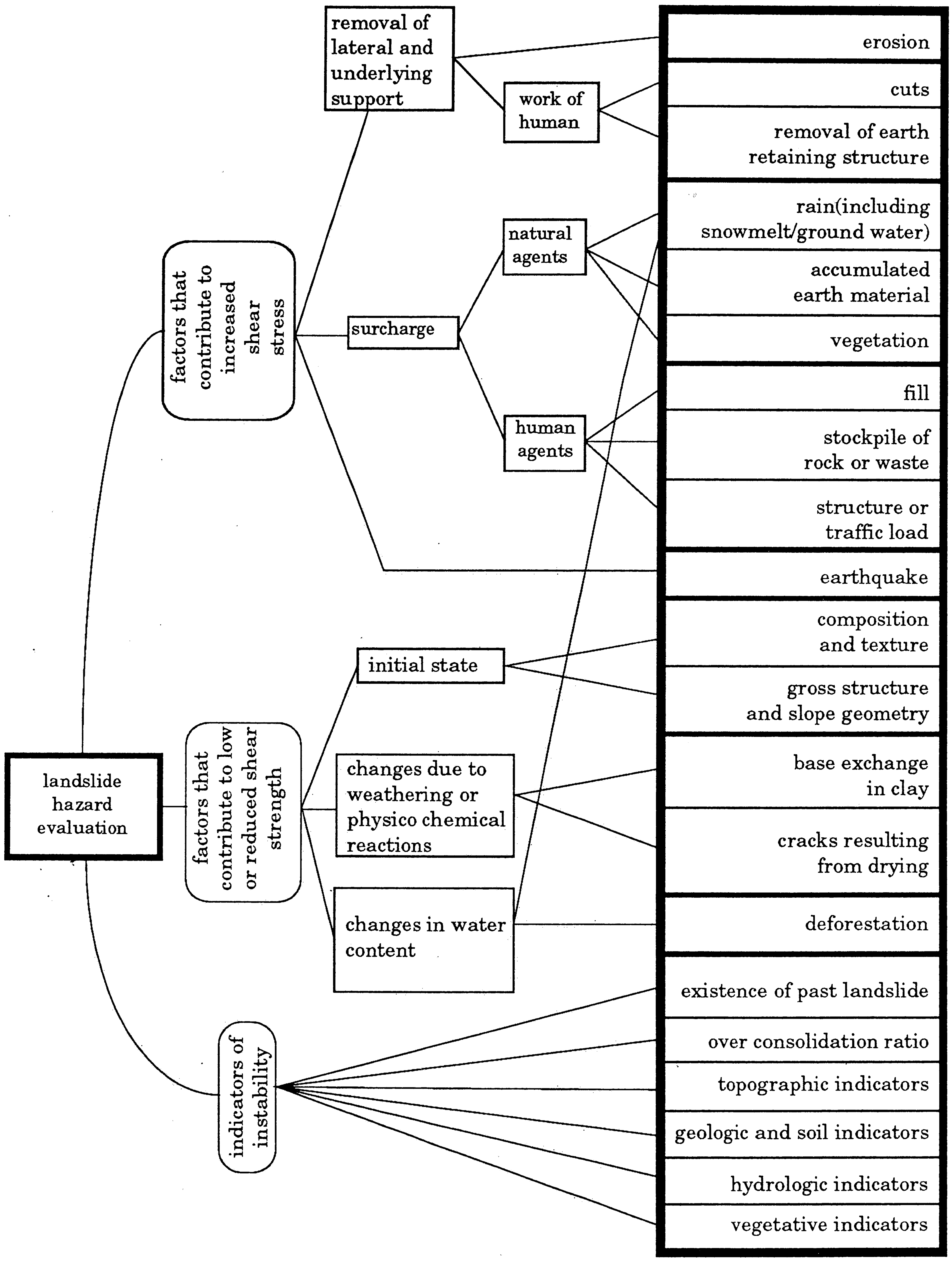


Figure 4-1: Factors used in Lanse Knowledge Base

processes, rules of thumb and judgements of experts are applied. Classification and scoring of factors which are at the end branches of each division, can be distinguished into three types. The first type is that the factors are rated into several levels of severity and quantified based on their degree of contribution in developing a favorable or unfavorable condition for a mass movement. Scoring of these levels depends a lot on judgement. As an example, a slope of 1.5 (horizontal) to 1 (vertical) which is commonly stable [Terzaghi and Peck 67], should have a lower score compared to a steeper slope, but a higher score compared to a less steep one. In the presentation of knowledge base, slopes are divided into four categories/classification from almost flat to very steep with their associated scores. Sources of knowledge used in this type are from previous attempts to formally classify the conditions, such as in Table 2-2 for classification of some factors, and in Table 4-1 for a general landform susceptibility. A much helpful study was presented in [Crozier 89] in appendix II which give characteristics of many factors/features that may indicate stability conditions. The study covered as many as 9 major groups with a total of 65 factors. In this work, two extreme descriptions, potentially stable and potentially unstable, are assigned according to the condition, severity, or existence of each factor. For example, regarding only a single factor (loading on upper slope), a slope is considered potentially stable if it does not have (*none*) loading on upper slope, and otherwise if *much* loading it is considered potentially unstable. Besides these sources, a number of other non-classification type of works have been used as the basis of classification within factors in this knowledge base. For example, a landslide record of a specific area studied the factors such as slope, soil type, inclination, vegetative cover with respect to the occurrence of slides under major storm in the city of Los Angeles [Cooke 84]. This work was used as source of information in developing the LANSE knowledge base

Topography	Landform or Geologic Material	Landslide Potential[a]
I. Level terrain		
A. Not elevated	Floodplain	3
B. Elevated		
1. Uniform tones	Terrace, lake bed	2
2. Surface irregularities, sharp cliff	Basaltic plateau	1
3. Interbedded-porous over impervious layers	Lake bed, coastal plain, sedimentary plateau	1
II. Hilly terrain		
A. Surface drainage not well integrated		
1. Disconnected drainage	Limestone	3
2. Deranged drainage, overlapping hills, associated with lakes and swamps (glaciated areas only)	Moraine	2
B. Surface drainage well integrated		
1. Parallel ridges		
a. Parallel drainage, dark tones	Basaltic hills	1
b. Trellis drainage, ridge-and-valley topography, banded hills	Tilted sedimentary rocks	1
c. Pinnate drainage, vertical-sided gullies	Loess	2
2. Branching ridges, hilltops at common elevation		
a. Pinnate drainage, vertical-sided gullies	Loess	2
b. Dendritic drainage		
(1) Banding on slope	Flat-lying sedimentary rocks	2
(2) No banding on slope		
(a) Moderately to highly dissected ridges, uniform slopes	Clay shale	1
(b) Low ridges, associated with coastal features	Dissected coastal plain	1
(c) Winding ridges connecting conical hills, sparse vegetation	Serpentinite	1
3. Random ridges or hills		
a. Dendritic drainage		
(1) Low, rounded hills, meandering streams	Clay shale	1
(2) Winding ridges connecting conical hills, sparse vegetation	Serpentinite	1
(3) Massive, uniform, rounded to A-shape hills	Granite	2
(4) Bumpy topography (glaciated areas only)	Morain	2
III. Level to hilly,transitional terrain		
A. Steep slopes	Tallus, colluvium	1
B. Moderate to flat slopes	Fan, delta	3
C. Hummocky slopes with scarp at head	Old slide	1

[a]1=suceptible to landslides; 2=suceptible to landslides under certain conditions; and 3=not suceptible to landslides except in vulnerable locations

Table 4-1: Key to landforms and their susceptibility to landslides after [Rib and Ta Liang 78]

The second type of scoring and classification is that each factor is ranked as to whether it exists or not. Therefore non-existence of a factor does not mean that there is no hazard at all, and thus, in scoring, it does not change the overall conclusion. On the other hand, if existence of a factor is positive, it might substantially modify the score which then affect the final conclusion. The third type of classification is almost the same as the second one. In this type the *number* of pieces of evidence, features or indications of a factor became the basis of judgment in classifying or scoring that factor. It is considered intuitively that the more the signs that may prove the existence of a factor the severer the condition is. Most of the outcome of these last two types are applied to the third group of factors in the factor structure. Majority of the knowledge in the third group are a collection of rules of thumb derived from experience. The factors are not formally classified in this group. Guidance to recognize signs or indications of mass movement are covered in a number of literatures [Sowers and Royster 78, Zaruba and Mencl 82, Sidle et al 85, Chowdhury 78, Bolt et al 77, Couperthwaite and Marshall a 89, Couperthwaite and Marshall b 89]. For example, pooling of surface water on the slope indicates poor drainage which further may indicate instability. Another example is the misalignment of fences or tilted mature tree which maybe indications of a slow mass movement. The preceding examples of guidances/tips belong to types of knowledge which are difficult to classify as to how severe a condition is if a certain feature exists. For example when comparing the severity of condition between an area where fences are misaligned by 10 cm, and another area where they are misaligned by 20 cm, it does not necessarily mean that the latter indicates a severer condition. The important thing is that the existence of these signs is a helpful indication in judging a condition.

After classifying factors and scoring them, the next step is to find out how these scores affect the overall score, how each factor contributes to the final evaluation, and how important is it compared to the others. Experts may have different opinions on the relative importance of the factors. Different judgments may be caused by the experiences of examiners or experts. These issues will be discussed in the following section as the next step in building the knowledge base.

4.1.3 Factor's contribution to the overall score

Result of a typical evaluation using the system is a hazard rating. It indicates how likely a given site or region is to undergo a mass movement. The evaluation is derived from the scores, or relative scores associated with each division. Score of each division is calculated from its own subdivision using their prescribed contributions or inference mechanism applied by the system shell. The same procedures are applied for subsequent divisions. During the evaluation process, each evidence of a factor at the leaf node will propagate and modify the scores of the parent nodes and all associated nodes beyond the parent nodes up to the node which contain the overall score. The contributions propagated upward are not the same for all factors. Different experts may have different opinion in assigning a level of contribution for a certain evidence, but generally they may have the same opinion on those factors that are more dominant than the others. Although every factor may become the single cause of a mass movement, for typical situations and for sites within the same area, there appears to be a number of common dominant factors. Therefore in the knowledge base there are factors which play a prominent part in the final conclusion. These factors are assigned a different weight of scoring depending on the area evaluated. For example, if the system is intended for evaluation in a typical urban area, factors that are considered dominant are:

- rainfall,
- slope geometry,
- existence of past landslides.

In order to utilize the inference mechanism in Geotox-PC the relative importance of each factor should be quantified. At this stage, the literature research gives limited help in providing the information which can be used as the basis for general comparison of importance between factors. To gather this information, a questionnaire was sent to a number of experts on the area of landslides, and their responses were averaged and used in the inference mechanism.

4.1.4 Questionnaire

The need of having weighted scores for factors in order to utilize the inference mechanism of Geotox-PC, and the lack of information in literature made it necessary to distribute questionnaires. A number of questionnaires were distributed in order to obtain experts' judgment. Some issues were considered when creating the format of the questionnaire. The first issue is that the intended system is to be used as a hazard rating tool, it will not try to explain the processes/mechanism involved in a particular slope failure. The second issue is that the questionnaire should be within the context of this stage of development of the system which is determining the weights that show the relative importance of a factor compared to the others as it is perceived by the experts. Classification of severity for a factor was not included at this stage and therefore in the questionnaire either. Classification within a factor increases the number of categories and also the differences between them. This situation is illustrated in Table 2-2 for only a few factors. The third issue considered for the questionnaire was that it should be easily processed and transferred to the system. Detailed questions were more likely to result in too many different opinions and make it more difficult to incorporate the result into the system. Therefore with the consideration of these three issues it was decided that the questions posed should only be on the relative importance of a factor, and should not be too detailed.

The questionnaire is divided into four groups. The first three groups represent the organization of knowledge. These groups of questions are shown in Tables 4-2, 4-3 and 4-4. The fourth group presents the relative contribution of each of the three groups (Table 4-5). *Confidence level of a factor* in the inference mechanism of the shell is simply translated from the questionnaire as the product of the *contribution (by how much)* and the *confidence to the contribution*, that is the product of the values in the second and third columns. Factors in each group of questions are compared directly between themselves, and the relative importance between factors from different groups is derived by using the values given in Table 4-5. Another group of questions that were asked were on the important factors that should be considered if the system is to be used in evaluations for a typical tropical urban environment. This group of questions are not shown here.

The most difficult consideration in creating this questionnaire was the implementation of the inference mechanism of Geotox into a simple question form. In the process, when a single evidence is supplied into the system, it fires a rule which carries a pair of hazard value and confidence factor which propagate upward. For disjunctive parent nodes, the values are updated using Formulas 3.1, 3.2, and 3.4. By examining these formulas, it is clear that the value of a new confidence factor (c_n) do not result by a simple mathematical operation between the old value (c_o) and the values which is just inserted to the system (c). Furthermore, the total of all confidence factors of leaf nodes is not necessarily equal to one. Therefore responding to a questionnaire which follows these formulas may be a complicated task. To alleviate the complexity of

Factors that may contribute to increased shear stress in slope/hillslope	Does this factor contribute ? [Y / N]	By how much ? [Scale **0 - 100**] 0 - min. contribution 100 - max. contribution	Your confidence in this ranking ? [Scale **0.0 - 1.0**] 0.0 - min. conf. 1.0 - max. conf.
Erosion			
Cuts			
Removal of earth retaining structure			
Rain (as surcharge)			
Accumulated earth material			
Vegetation			
Fill			
Stockpile of rock or waste			
Structure or traffic load			
Earthquake			

Table 4-2: Group A in questionnaire

Factors that may contribute to low or reduced shear strength in slope/hillslope	Does this factor contribute ? [Y / N]	By how much ? [Scale **0 - 100**] 0 - min. contribution 100 - max. contribution	Your confidence in this ranking ? [Scale **0.0 - 1.0**] 0.0 - min. conf. 1.0 - max. conf.
Composition and texture			
Gross structure and slope geometry			
Base exchange in clay			
Cracks resulting from drying			
Rain (affecting pore pressure/water content)			
Deforestation			

Table 4-3: Group B in questionnaire

Factors as indicators of slope instability	Does this factor contribute ? [Y / N]	By how much ? [Scale **0 - 100**] 0 - min. contribution 100 - max. contribution	Your confidence in this ranking ? [Scale **0.0 - 1.0**] 0.0 - min. conf. 1.0 - max. conf.
Existence of past landslide			
Over consolidation ratio			
Topographic indicators, such as: misalignment of fence, hummocky or rumpled surface, bulging at toe etc.			
Geologic and soil indicators, such as: loose sand, soft clay, fractures, bedding planes etc.			
Hydrologic indicators, such as: ponded water on the slope, seep/spring, alternate layers of pervious and impervious etc.			
Vegetative indicators, such as: tilted mature trees, irregular vegetation pattern, clearcutting etc.			

Table 4-4: Group C in questionnaire

	Contribution (%)
A. Factors that contribute to increased shear stress	...
B. Factors that contribute to low or reduced shear strength	...
C. Factors as indicators of slope instability	...
Total	100%

Table 4-5: Question on group contribution

analysis the questionnaire was put into a simple form as much as possible. The questionnaire is intended to establish the *relative difference between confidence levels* and not the confidence levels used in the system. Then using the relative values from the result of the questionnaire, Formulas 3.1, 3.2 and 3.4 were applied to obtain a set of confidence levels. This process was repeated by trial and error, and stopped after the overall confidence level was higher than a specified value but still less than one. The last set of values from this process was used in the system. A separate program was developed in Turbo Prolog version 2.0 to perform the iterations.

Table 4-6 presents the results of this process. The first column is the factor number, for example A.1 is the first factor from group A in the questionnaire. The second column is the average of relative confidence levels of each factor from all the responds. Relative confidence is the product of the factor's contribution and the confidence to that contribution. The third column is the relative confidence level to confidence level of the first factor, A.1. The last column is the new set of values of confidence resulting from the trial and error process.

4.2 Stage of development

After establishing contribution of each factor, the overall hazard value and its associated confidence level can now be determined. The next task is to determine the site rating. In the process of evaluation, the more user inserts data into the system, the higher the overall confidence level will be. During a session, in order for the system to give a conclusion, the overall confidence factor should be built up beyond a specified minimum value. Below this value, it is considered that the data given are not sufficient to arrive at a conclusion. Conclusion is performed in frames which are part of the associative nodes. It is derived by using the values of the nodes connected to the slots of the frames. Qualitative ratings assigned to a site depend on the overall hazard value. Four

No.	Average relative confidence with total of 0.995	Average relative confidence to A.1	Confidence level used in the system
A.1	0.03715	1.00000	0.170
A.2	0.05487	1.47699	0.251
A.3	0.03800	1.02303	0.174
A.4	0.02542	0.68450	0.116
A.5	0.01878	0.50554	0.086
A.6	0.00375	0.10096	0.017
A.7	0.04985	1.34200	0.228
A.8	0.04021	1.08226	0.184
A.9	0.03127	0.84163	0.143
A.10	0.04121	1.10928	0.189
B.1	0.06216	1.67325	0.284
B.2	0.04031	1.08500	0.184
B.3	0.02209	0.59451	0.101
B.4	0.05079	1.36705	0.232
B.5	0.09826	2.64489	0.450
B.6	0.03219	0.86646	0.147
C.1	0.08298	2.23351	0.380
C.2	0.00798	0.21494	0.037
C.3	0.08982	2.41777	0.411
C.4	0.05056	1.36097	0.231
C.5	0.05273	1.41941	0.241
C.6	0.06434	1.73210	0.294

Table 4-6: Relative confidence levels

ranges of values were classified: *no hazard*, *slight hazard*, *moderate hazard*, and *high hazard*. In this stage, the selected ranges of values and minimum confidence level are considered tentative, and need a further fine tuning by using actual landslide cases.

In the case of high hazard rating, it will raise the question of what measures to take, whether the measures are economically justified, or whether there is a need to conduct further field and laboratory investigations. There will be more complex factors to consider since recommendation on preventive measures should be based on the nature of the problem which involves recognition of the types of movement and mechanisms of possible failures. However, these analyses are beyond the scope of the current research. At the present development, knowledge base is not sufficient to produce a reliable suggestion on preventive measures. Figure 4-2 presents the current capability of the system which is provided by the knowledge base. To enable the system to give more reliable recommendations on landslide control measures, more sections of knowledge base should be added.

The expert system was developed to allow for a flexible arrangement of knowledge in the knowledge base. Such a system will then allow adding and/or changing the existing knowledge base, thus provide the capability to update the system periodically as more information is available from landslide problems and associated research. Users or experts may disagree on all the steps taken during the development of this knowledge base (structure, classification, and contribution), or values determined for conclusion. Therefore, this flexibility is considered necessary.

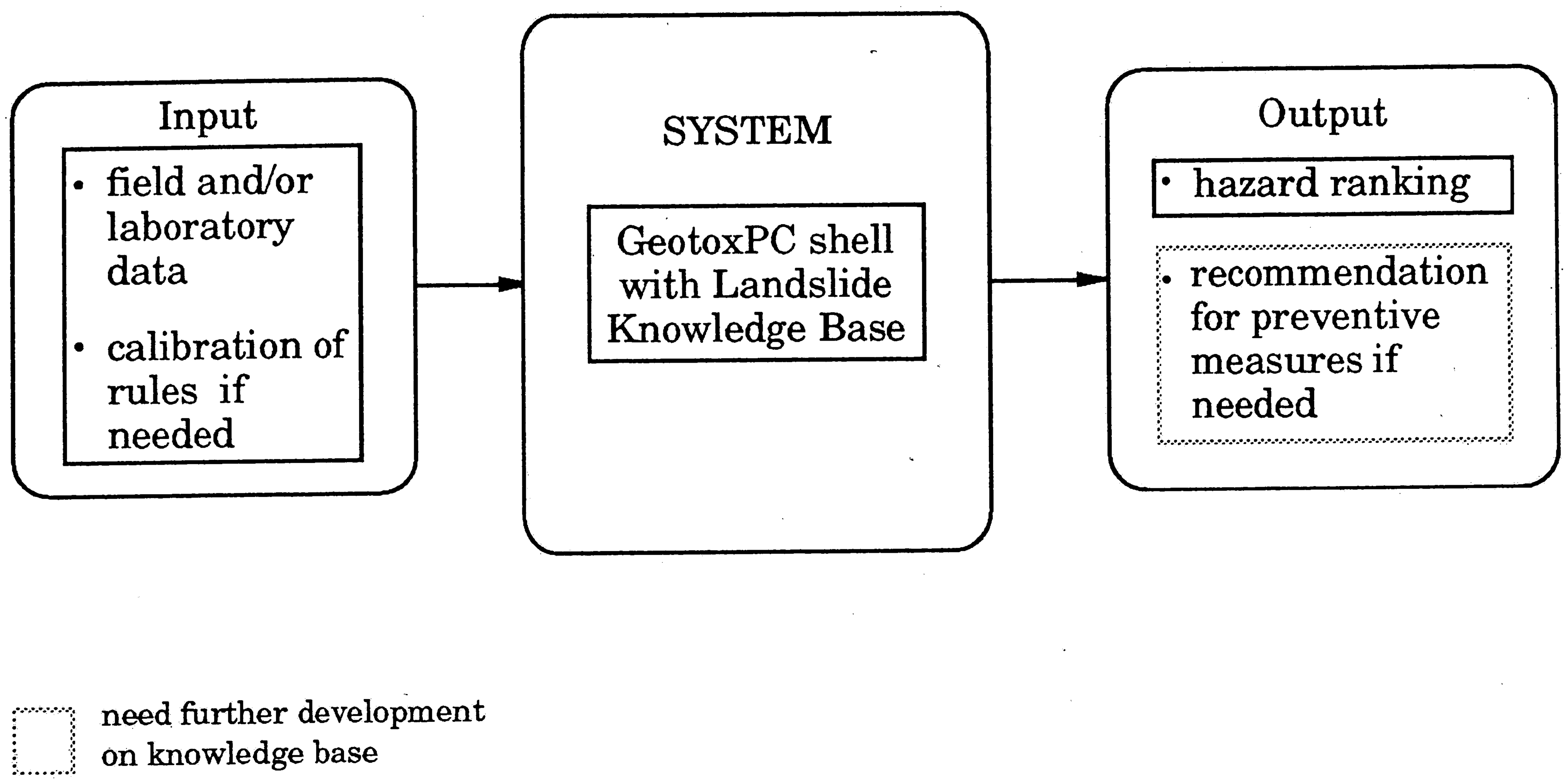


Figure 4-2: I/O diagram of current Lanse Knowledge Base

4.2.1 Consultation

During consultation, user will be prompted with some questions regarding the conditions of the site under investigation. User may respond by choosing the appropriate letter which he considers best describe the conditions, or asking the system's reason for prompting the question by selecting options such as *what*, *why* and *how*. If there is no data concerning a specific factor, the user may ignore the question and continue to the next question. The order of questions posed is determined by the structure of the factors. However, if the user needs to answer the questions in his/her order of preference, he/she can do so by using option *volunteer*. Mistakes in supplying data can be rectified with the option *change*. Figure 3-1 describes some of these options.

There are three types of questions asked: 1)multiple choice with increasing *degree* of a factor such as average height of precipitation, 2)a yes-no question, 3)multiple choice with increasing *number* of signs or characteristics which shows that a certain condition does or does not exist at the site, such as features indicating a disrupted drainage. Choices made will represent user's assessment of the hazard of the particular factor and its associated confidence level. User can examine the state of knowledge during data input, to see which factors have already been inserted with their values, and also the overall values. This can be done by selecting options *summarize* or *conclude*.

For areas where some unique or extreme environmental condition exist, modification of the knowledge base maybe necessary. Modification might also be performed whenever the user considers it appropriate. Options to perform these modifications are available in sub-menu *revise*. System's pair of values for each factor can be examined by using *show rules*. The options *add rules* and *delete rules* can be selected to remove or add a rule. If the user considers that the structure of a factor is not acceptable, he/she can modify it by choosing options *delete relation* and *add relation*. The new structure can be seen in option *show relation*.

In a condition where there are too few known facts of a site, which renders the system unable to draw a conclusion with sufficient confidence, the system might suggest to the user to collect and enter more data. During collection of additional data, the current content of data base can be saved into a file by using option *save as file*. Later, this file can be retrieved by using option *consult file*.

It is not uncommon that some data for evaluation will not be readily available, or will be missing. For situations such as this, the expert system is designed to perform evaluations with incomplete data using a probability approach. This can be done as long as the current confidence level still reaches a certain minimum level. The unspecified factors will not affect the system in giving an evaluation during a consultation.

An example of a consultation can be seen in the Appendix. Data used in this example were taken from an inspection report of landslide on the Mantaro river, Peru, April 25, 1974 [Lee and Duncan 75]. The system evaluation coincides well with the actual occurrence.

Chapter 5
Conclusion

A knowledge based expert system, namely Lanse, has been built to help engineers in their primary evaluation of stability conditions of suspected slopes or hillslopes. A probability approach was selected as a method of assessment, therefore the result of the evaluation is given in terms of hazard rating and its associated confidence level.

The knowledge base was built in part by averaging a number of experts' judgment collected by a questionnaire. Therefore the result of the system's evaluation may be more reliable for typical conditions which may or may not lead to landslides. Predetermined hazard values and confidence levels have been utilized in the system. However, flexibility is provided for the user to modify the system to adjust it to work with specific or extreme conditions at a given site.

Knowledge base needs a continual updating as understanding on landslide problems improves. This updating maybe in refining the structure and the predetermined values. For further research, substantial improvement can be made by expanding the functions of the system. Besides hazard rating, a function maybe be added to enable the system to give reliable recommendations on measures to take in preventing or avoiding damages caused by landslides. Knowledge base should then be focused on explaining the mechanism involved in failures.

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Appendix

The following items are quoted or inferred from report of inspection on landslide of april 25, 1974 on the Mantaro River [Lee and Duncan 75]. Data used in this example are condition of slopes prior to the landslide disregard whether those conditions caused the sliding.

- ...... evidence of past and current ground movement......
- ...... side slopes of the order of three to four horizontal to one vertical......
- .....deeply weathered sedimentary rocks (shales, sandstone & limestone)......
- ..... evidence of extensive faulting.....
- ..... climate in this zone is concentrated wet and dry......
- ..... annual rainfall 702 mm of which about 95% falls during the period Oct. through april......
- ..... heavy concentrated rainfall......
- ..... extensive landslides have occurred......
- ..... scarps appear to be fairly fresh and large in size......
- in Figure 2, it is seen patchy vegetation
- In Figure 3 (prior to landslide)
    - ..... suggesting existence of faults......
    - ..... midway between the Mantaro river and the crest of the mountain was located the town or village.....
    - near the top 40°, near the bottom 50°
    - 10 haciendas(large farms) on the slope
    - 6 creek (ravine) on the slope
    - 5 lagunas (small lakes) on the slope
    - 4 manantial (spring & small stream) on the slope
    - cracks or fractures
    - scarp > 10m around the top
    - scarp < 10m parallel and perpendicular to the large scarp
- ..... the slope is covered with thick (100-200m estimated) layer of weathered alluvium or detritus.....
- ..... cobbles, gravel, sands and clays without significant cementation.....
- ..... extensive layers of interbedded sandstones and clay .....

- ..... the bedding in the sedimentary rock zone dips approximately parallel to the ground surface.....
- ..... providing ready seepage path for ground water percolation.....
- ..... natural instability of this formation is clearly indicated by the the extensive fractures and amount of broken rocks......
- ..... the area is known to be seismically active ......
- between 1911-1974 the largest magnitude is >6 in Richter scale(Fig46)

Type LANSE

LOGO
MAIN MENU

[GO]

Facility Name : Mantaro River
Location : Mantaro River, Peru
Reviewer : Muhiddin

How is the seismic activity of the region ?.

a) Non-seismic zone.
b) The highest magnitude ever is <4 in Richter scale
c) The highest magnitude ever is between 4 and 5.5 in Richter scale.
d) The highest magnitude ever is >5.5 in Richter scale.

Please answer a.,b.,c.,d.
[a b c d]>d
Earthquake HAZARD: 8.75
SITE HAZARD: 8.75

What is the extent of erosion in the toe of the slope ?.

a) No apparent erosion.
b) Slight to moderate.
c) Moderate to severe.
d) severe.

Please answer a.,b.,c.,d.
[a b c d]>d

Erosion HAZARD: 8.75
SITE HAZARD: 8.75

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If the slope or surroundings are cuts, how different is the cut's inclination to the average natural slope on the area ?.

a) No cuts.
b) Less steep.
c) Steeper with slope less than 3(H):1(V).
d) Extremely steeper with slope greater than 3(H):1(V).

Please answer a.,b.,c.,d.

[a b c d]>a
Cuts HAZARD: 1.25
SITE HAZARD: 5.04

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Is there any recent removal of retaining structure on or adjacent to the site ?.

a) No
b) Yes

Please answer a.,b.

[a b]>a
Removal of earth retaining structure HAZARD: 1.25
SITE HAZARD: 4.34

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What is the highest weekly precipitation ?.

a) 0 mm - 50 mm
b) 50 mm - 100 mm
c) 100 mm - 200 mm
d) > 200 mm

Please answer a.,b.,c.,d.

[a b c d]>d
Rain (including snowmelt/ground water) HAZARD: 8.75
SITE HAZARD: 7.03

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On or around the slope, is there any recent accumulation of earth material ?.

a) No.

b) A little amount.
c) Large amount.

Please answer a.,b.,c.

[a b c]>a
Accumulated earth material HAZARD: 1.5
SITE HAZARD: 6.93

How do you describe the vegetation on the site ?.

a) No vegetation.
b) Cultivated slope.
c) Ivy or grasses.
d) Low shrubs, trees, or native vegetation.

Please answer a.,b.,c.,d.

[a b c d]>d
Vegetation HAZARD: 8.75
SITE HAZARD: 6.93

On or at the upper part of the slope, there is:

a) no fill or construction of fill.
b) thin and small fill or fill with slope < 2(H):1(V).
c) thick fill or fill with slope > 2(H):1(V).

Please answer a.,b.,c.

[a b c]>a
Fill HAZARD: 1.5
SITE HAZARD: 6.31

On or at the upper part of the slope, there is :

a) no recent stockpiling of rocks or waste materials.
b) small amount of recent piling of rocks or waste.
c) abundant recent piling of rocks or waste materials.

Please answer a.,b.,c.

[a b c]>a
Stockpile of rock or waste HAZARD: 1.5
SITE HAZARD: 5.99

On or at the upper part of the slope, there are:

a) no structure/railway/road or their construction.

b) rare or a few structures/railways/roads.
c) many structure or heavy and frequent traffic loads.

Please answer a.,b.,c.
[a b c]>b
Structure or traffic load HAZARD: 5
SITE HAZARD: 5.96

What are the majority of composition and texture ?.

a) Bentonite or organic material.
b) Sedimentary clay or shale, or volcanic tuff, or platy material.
c) Loess or sedimentary rocks.
d) Other than above.

Please answer a.,b.,c.,d.
[a b c d]>b
Composition and structure HAZARD: 6.25
SITE HAZARD: 5.99

What is the inclination of the site.

a) Less than 50(H):1(V) (=1.15 deg.),or with height < 2m.
b) Between 1.15 degree and 15 degree.
c) Between 5 and 15 degree without unfavorable condition such as faults, bedding planes towards free surface, cleavage.
d) Greater than 15 degree, or greater than 5 degree with unfavorable structure condition.

Please answer a.,b.,c.,d.
[a b c d]>d
Gross structure and slope geometry HAZARD: 8.75
SITE HAZARD: 6.14

Concerning leaching which of the following is best describe the site

a) No apparent leaching, or infiltration of waste water or chemicals.
b) Small amount of leaching, or infiltration of waste water or chemicals.
c) Extreme leaching, or infiltration of waste water or chemicals.

Please answer a.,b.,c.
[a b c]>a
Base exchange in clay HAZARD: 1.5
SITE HAZARD: 6.06

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What is the effect of drying on or around the top of the slope ?.

a) No cracking.
b) A few and thin cracks, or cracks hidden by vegetation.
c) Large cracks, or steady enlarging cracks.

Please answer a.,b.,c.
[a b c]>c
Cracks resulting from drying HAZARD: 8.75
SITE HAZARD: 6.27

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Concerning the forest on the slope, which of the following is best describe its condition ?.

a) There has never been any forest, or the forest has never been touched or altered by human activity.
b) The forest underwent selective and patchy tree cutting.
c) The forest was converted to cultivated land.
d) Total clear-cutting without replanting or cultivation.

Please answer a.,b.,c.,d.
[a b c d]>b
Deforestation HAZARD: 3.75
SITE HAZARD: 6.19

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From the history of the site, which of the following is true.

a) There has never been any mass movement in the area.
b) There is old landslide deposit on or around the slope.
c) There has been recent mass movement/landslide in the area.

Please answer a.,b.,c.
[a b c]>c
Existence of past landslide HAZARD: 8.75
SITE HAZARD: 6.64

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How many of the following condition can best describe the site.
- Unconsolidated or weakly consolidated soil.
- The site has buried pockets of unconsolidated colluvium.
- The site is excavation on heavily over consolidated material.

a) None. b) One or more of the above.
Please answer a.,b.
[a b]>b

Over consolidation ratio HAZARD: 8.75
SITE HAZARD: 6.65

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How many of the following features can best describe topographic conditions of the site ?.
- Convex slope.
- Bulging near the toe.
- Steep curved scarp at the upper edge of the slope.
- Misalignment of fences or poles occurs on the site.
- Abrupt and irregular changes in slope and drainage pattern.
- Irregular, hummocky, or rumpled surface.

a) None. b) 1 to 3. c) 4 or more.
Please answer a.,b.,c.
[a b c]>c
Topographic indicators HAZARD: 8.75
SITE HAZARD: 7.01

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How many of the following features can best describe geologic and soil conditions of the site ?.
- The soil consists of clay with qu of less than 0.5 kg/cm2
- The site is predominantly soft clay with a lot of bentonite.
- The soil consists of loose sand (silty, clayey).
- The soil consists of clay with sand or silt partings.
- Underlying is metamorphic rock with well developed foliation planes.
- Joints and fractures exist on or around the slope.
- Bedding planes align more or les parallel to the slope.
- Cracks appear near the top.
- The site consists of shallow soil over hard impermeable rocks.

a) None. b) 1 to 2. c) 3 or more.
Please answer a.,b.,c.
[a b c]>c
Geologic and soil indicators HAZARD: 8.75
SITE HAZARD: 7.1

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How many of the following features can best describe hydrologic condition of the site.
- The site consists of alternate layers of pervious and impervious materials.
- Near surface drainage (wet area) exists on the slope.
- Ponded water appears on the slope.
- Seep and spring exist on the slope.
- Above or on the slope is road with inadequate drainage or blocked ditches.

a) None b) 1. c) 2 or more.

Please answer a.,b.,c.
[a b c]>F1
Press any key to continue

Some HYDROLOGIC FEATURES show disrupted drainage
which is one of the cause of mass movement

[a b c]>c
Hydrologic indicators HAZARD: 8.75
SITE HAZARD: 7.18

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How many of the following features can best describe vegetative conditions of the site.
- Presence of tilted or curved mature trees/ jackstrawed.
- Irregular vegetative pattern/ disturbed vegetation/localized differences in vegetation.
- Clear-cutting/ deforestation has been done.
- Existence of tree that split up at the bottom, or tearing of shrubs.
- Presence of characteristics plants which associated whit landslide.

a) None. b) 1. c) 2 or more.

Please answer a.,b.,c.
[a b c]>[ENTER]
Press any key to continue

END OF QUESTIONS
Returning to main menu

Press any key to continue

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[CONCLUDE]

Facility Name : Mantaro River
Location : Mantaro River, Peru
Reviewer : Muhiddin

The evidence at the site STRONGLY suggests that
MODERATE over burden stress (in addition to soil weight)
at the site, and
GREAT consequences is VERY PROBABLE.
The seriousness of the situation is RELATIVELY HIGH.

Overall the site in its natural state receives a
HIGH HAZARD rating

[Summarize ? y/n]y

SITE CHARACTERISTICS

FACTOR NAMES	SCORES	Conf
Work of human	1.25	0.30
Removal of lateral and underlying support	3.04	0.35
Natural agents	8.52	0.48
Human agents	2.14	0.32
Surcharge	6.66	0.56
Factors that contribute to increased shear stress	5.96	0.64
Initial state	6.97	0.33
Changes due to weathering or physico-chemical reactions	7.61	0.25
Changes in water content and pore pressure	8.33	0.49
Factors that contribute to low or reduced shear strength	7.89	0.61
Indicators of instability	8.75	0.61
Overall landslide hazard evaluation	7.18	0.83

OBSERVATIONS

FACTOR NAMES	SCORES	Conf
Earthquake	8.75	0.19
Erosion	8.75	0.17
Cuts	1.25	0.25
Removal of earth retaining structure	1.25	0.17
Rain (including snowmelt/ground water)	8.75	0.47
Accumulated earth material	1.50	0.09
Vegetation	8.75	0.02
Fill	1.50	0.23
Stockpile of rock or waste	1.50	0.18

FACTOR NAMES	SCORES	Conf
Structure or traffic load	5.00	0.14
Composition and structure	6.25	0.28
Gross structure and slope geometry	8.75	0.18
Base exchange in clay	1.50	0.10
Cracks resulting from drying	8.75	0.23
Deforestation	3.75	0.15
Existence of past landslide	8.75	0.38
Over consolidation ratio	8.75	0.04
Topographic indicators	8.75	0.41
Geologic and soil indicators	8.75	0.23
Hydrologic indicators	8.75	0.24

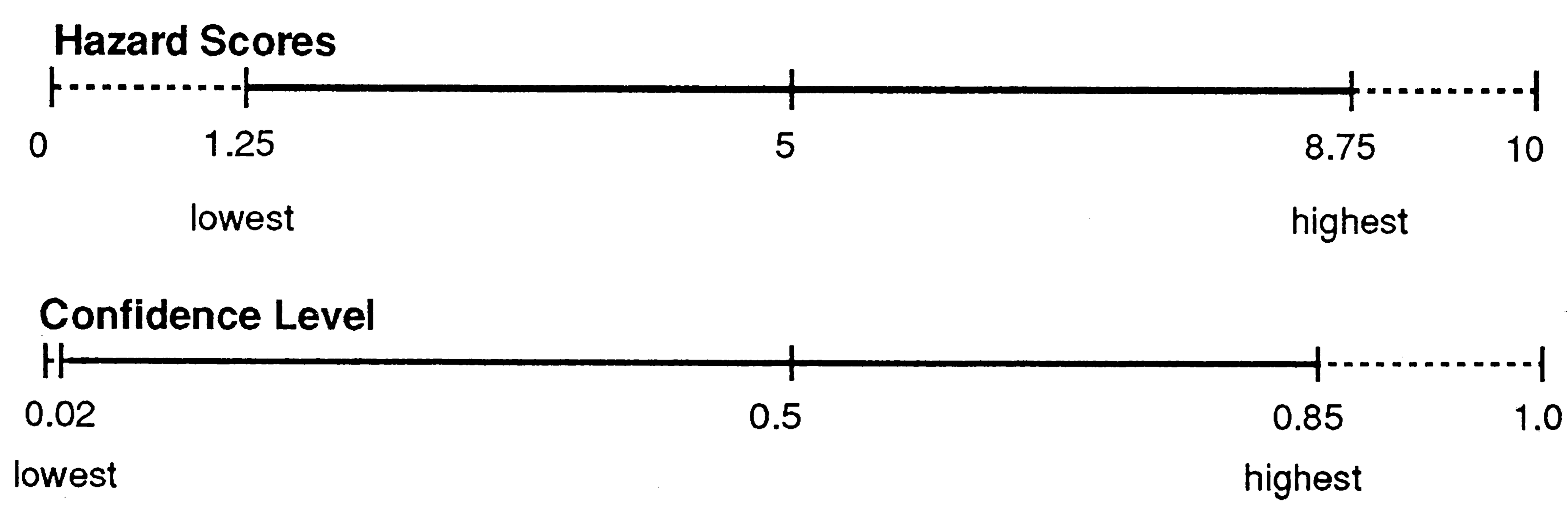
UNKNOWN FACTORS

vegetativeIndicators

[QUIT]

NOTE:

SCALES



Vita

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The author was born in Jakarta, Indonesia, on the 30^{th} of July,1960, the son of Hammad and Hadawiyah Muhiddin.

EDUCATION
Lehigh: M.S., Civil Engineering.
Institut Teknologi Bandung, Indonesia: Diploma, Civil Engineering, Oct 1985.

HONOR
MUCIA GPT-II scholarship.

EXPERIENCE
Hasanuddin University, Indonesia: Assistant Lecturer, Aug 1986-Jun 1987 and to date, during training, still employee at this university.

PUBLICATION
Muhiddin et al., "Use of Knowledge-based Expert Systems For Controlling Landslides in Tropical-Urban Environment", *1^{st} Caribbean Conference on Artificial Intelligence, Trinidad, Dec.4-5, 1989,* U. of the West Indies, St. Augustine, Trinidad, Feb. 1990, pp 63-74.